DOCUMENT RESUME

ED 229 238 SE 041 438

AUTHOR Champagne, Audrey B.; And Others
TITLE Effecting Changes in Cognitive Structures Amongst Physics Students.
PUB DATE 83
NOTE 41p.; Paper presented at the annual meeting of the American Educational Research Association (Montreal, Canada, April, 1983).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Change Strategies; Cognitive Processes; College Science; Comprehension; *Concept Formation; Elementary School Science; Elementary Secondary Education; Higher Education; Instructional Design; *Physics; Problem Solving; *Schemata (Cognition); *Science Education; *Science Instruction; Secondary School Science; Teaching Methods
IDENTIFIERS Misconceptions; Science Education Research

ABSTRACT

The existence, before any formal physics instruction, of schemata which lead to an idiosyncratic interpretation of real world events, which physicists see as exemplifying principles of physics, is now well established. Because these interpretations are often at variance with physicists' interpretations, they have been labeled, among others, "alternative schemas," or "misconceptions." Studies suggest that these schema are extremely resistant to change during formal instruction, particularly in mechanics. Consequently, there has been considerable interest in attempts to design instruction to facilitate cognitive structure change. Several strategies, derived from detailed descriptions of the cognitive structures and problem-solving strategies of individuals with various levels of physics and expertise, appear to be promising. Provided in this report is the current status of investigations of the extent to which the strategies do facilitate change, identification of strategy features which may be significant in promoting change, and the appropriate modification of the strategies in light of their use. The report includes a brief description of the broad structure of the instruction and probes used to gather information about aspects of students' cognitive structures (middle school students: N=13 and college students N=6), results (indicating a change in cognitive structure of the college student), and conclusions. (JN)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED229238

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
✓ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

Effecting Changes in Cognitive Structures Amongst Physics Students

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY
Richard F. Gunstone
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Audrey B. Champagne
L.R.D.C., University of Pittsburgh

Richard F. Gunstone
Monash University
Victoria, Australia

Leopold E. Klopfer
L.R.D.C., University of Pittsburgh

Paper presented at the symposium on Stability and Change in Conceptual Understanding, annual meeting of the American Educational Research Association, Montreal, April 1983

SE041438

In our paper at the related symposium at the 1981 AERA meeting (Champagne, Klopfer, & Gunstone, Note 1), we used a statement about physics teaching made by Charles Judd 75 years ago to set a context for our subsequent arguments. The context for the present paper is well introduced by a much more recent and, strangely, an apparently ignored view expressed by Easley (1971):

> Children and adults often express quasi-Aristotelian dynamics concepts resembling momentum, acceleration, and the vectorial decomposition of gravitational attraction. Unfortunately, most curricula in physics suggest a purely descriptive (kinematical) investigation of position and time, and provide no means for people to test their own theories of dynamics and to restructure them (p.156).

Introduction

The existence, before any formal physics instruction, of schemata which lead to an idiosyncratic interpretation of real world events which physicists see as exemplifying principles of physics is now well established. Because these interpretations are often at variance with physicists' interpretations, they have been labelled alternative schemas, misconceptions, alternative frameworks, personal models of reality etc. Although forms of such idiosyncratic cognitive structure have been shown in a variety of content areas, elementary mechanics has been the focus of a number of studies. Our own work has estabalished the common existence of cognitive structures which are logically antagonistic to the tenets of

physics among students beginning a formal study of mechanics (Champagne, Klopfer, Solomon, & Cahn, Note 2; Gunstone, Champagne, and Klopfer, 1981), and among students who have successfully completed an introductory physics course (Champagne, Klopfer, & Anderson, 1980; Gunstone & White, 1981). A review of studies which have explored the nature of pre-instruction mechanics cognitive structures is given elsewhere (Champagne, Klopfer, & Gunstone, 1982).

As the number of studies of pre-instruction cognitive structures has grown it has become clear that these schema are extremely resistant to change during formal instruction, particularly in the area of mechanics. As a consequence, there has been a considerable growth of interest in attempts to design instruction to facilitate cognitive structure change. In considering this instructional problem, we have previously argued instructional strategies which existing research and current perspectives suggest to be promising (Champagne, Klopfer, & Gunstone, Note 1). These strategies were derived from detailed descriptions of the cognitive structures and problem solving strategies of individuals with various levels of physics expertise. Aspects of these descriptions have subsequently been elaborated (Champagne, Klopfer, & Gunstone, 1982).

It is these strategies which underpin the work described in the present paper. We report the current status of our investigations of the extent to which the strategies do facilitate change, the identification of particular features of the strategies which may be of significance in promoting change, and the appropriate modification of the strategies in the light of use of them. Thus far, one general instructional approach has been used with two very different groups - middle school students designated as academically gifted and with a demonstrated interest in science in Pittsburgh, and non-physics-major science graduates studying to

become high school science teachers in Victoria. Because of the considerable differences in the two groups there was some difference in the detail of the instructional approach used with each. To this stage, different analyses have been applied to the data from each group. Hence the paper firstly gives brief descriptions of the broad structure of the instruction and the probes used to gather information about aspects of students' cognitive structures, then presents some data and the analyses of these data which have so far been undertaken separately for each group before finally presenting some conclusions.

Instruction

The instruction was designed to provide considerable opportunity for students to argue their own interpretations of both specific events and general relationships. It began with a substantial discussion of the question "what are some of the things we can we say about the relationships between force and motion?" and subsequently explored areas including methods of describing motion and force, falling bodies, motion on inclined planes, forces on objects in a variety of contexts. Demonstrations and direct experience were used. Students were frequently asked to make predictions about the outcome of particular real situations, and then asked to defend the prediction. This latter technique is in effect a discussion-based adaption of the Demonstrate, Observe, Explain form of testing designed by Champagne and Klopfer (see Champagne, Klopfer, & Anderson, 1980; Gunstone & White, 1981). Group sizes were small and the time spent with each group reasonably long (details for each group are given below).

Probes of cognitive structure

Assessments were made of aspects of students' cognitive structures before and after the instruction. A variety of probes were used, with some being group administered and some being individual interviews. We have not included in this paper a detailed discussion of the possible methodologies which could have been used, nor a detailed discussion of why those which were used were chosen. However some brief comments are made about the choice of probes.

Three group administered probes of cognitive structure were used. These have all previously been used in psychometrically oriented studies of cognitive structure, and were essentially chosen because their form allowed for the application of similar scaling methods to the data. Two probes used the same concepts, while the third used a subset of these concepts. As a consequence, data analyses from the three tests allowed consideration of validity issues associated with the extent to which the three measures converged. The three methods were a free sort task, a tree construction task, and a word association task. Each is described below.

The meanings ascribed to cognitive structure in studies using instruments such as the above are strongly based on theories of semantic memory and can be characterized by a number of common features. These include: (1) They refer to patterns of relationships between concepts; (2) They explicitly consider only concepts, while the existence of other cognitive entities is quite implicit; (3) They do not differentiate any types of elements, units or dimensions of cognitive structure; (4) They assume a rather stable organization; (5) They are not connected with issues of concept utilization which arise when considering understanding

of text, concept formation, or problem solving. It is clear that our earlier work (cited above) has been concerned with issues represented in point (5). Hence we used two individually administered probes which are in essence structured interviews. The first of these was a concept mapping task (termed ConSAT) and the second a real situation for which students made predictions, observed, described the knowledge they used, and evaluated a set of predictions and explanations given by other students.

Free Sort Task

This concept classification and categorization task required students to categorize 17 physics concepts. The concepts are listed in the caption to Figure 1. No criteria for categorization were suggested.

Various versions of free sort tasks have been used previously (e.g., Gorodetsky & Hoz, 1981; Miller, 1969; Shavelson & Stanton, 1975). In our version of the task, student instructions began with an example of two ways in which 7 non-physics terms could reasonably be classified in order to emphasize the absence of a single, correct answer to the task. The instructions then reiterated the absence of a right answer, indicated that the words to be classified were on cards inside an envelope provided, asked that the words be classified into "categories that include words that you think belong together", and pointed out that any number of categories was possible and that any category could contain any number of words. On completion of the card categorizing, students transferred their grouping to an answer sheet containing 12 boxes. No time limit was applied to the task.

Tree Construction Task

Fillenbaum and Rapoport (1971) devised this task as a method of measuring semantic distance between concepts. In our task, students were

given the same 17 concepts used for the free sort task. Students were instructed to "pick the two words from the list which you think are most related to each other", write the words in the centre of a page, and connect them with a line numbered 1. This was then built on by adding another word from the 17 which was seen as "most related" to one of the two already used, then connecting with a line numbered 2. Either this procedure continued or a new tree was started depending on the student's judgement of the extent of relatedness. Instructions required students to eventually join up trees if they had produced more than one so that the total response to the task comprised the 17 words and 16 numbered connections. Again, no time limit was applied.

Word Association Task

Tasks required free associations to a given stimulus within a fixed time period - which is usually one minute - having been quite widely used in studies of cognitive structures of physics students (e.g., Johnson, 1965; Preece, 1976; Shavelson, 1972). Our version of the task used 5 stimulus words from the 17 used in the preceding two tests (force, mass, speed, inertia, change of motion), with one minute being allowed for each set of responses. In addition, students were given the same sentence completion task used by Gunstone (1980; Note 3). After completing responses to a stimulus, students wrote a sentence for each response which showed "how you think your [response] is connected with" the stimulus in order to give information about the nature of the associative link.

ConSAT Task

This task involves students producing a concept map. Concept maps have been used previously in investigations of cognitive structure (e.g., Champagne, Klopfer, Desena, & Squires, 1981). In the present usage, the ConSAT task was administered individually so that appropriate

follow-up questions could be asked throughout the interview. Each interview was tape recorded.

Initially a practice example involving 10 parts of the human body was given. The 10 parts were sorted by the student into "words you recognize" and "words you don't recognize". The student was then instructed to arrange the words in the recognized pile on a sheet of paper "in a way that shows how you think about them ... to show the relationships between the words". Students were overtly encouraged to think aloud during this process. When the arrangement was complete, the student was questioned about reasons for the representation which had been produced. This information was recorded on the same sheet, and the possibility of other arrangements discussed. An identical procedure was then followed for the physics concept map except that, after sorting into the two piles, students were asked to tell the interviewer the meaning they understood for each concept in the recognized pile. The concepts used were the same 17 used for the free sort and tree construction tasks.

Real Event Task

This task, again administered in an individual interview context, followed the form of the Demonstrate, Observe, Explain task mentioned above together with some additional material. For a series of events based on a single situation, students gave predictions, explained the basis of their prediction (knowledge used, relevant personal experience etc.), observed the event, and considered any differences between prediction and observation. In addition, prior to observing the event, students considered a set of answers given on previous occasions and were asked to describe the way in which various concepts were being used in these answers. As with the ConSAT task, a non-physics task involving the same process was given first. The whole interview was tape recorded.

Pre- and Post- tests

Identical test forms were given before and after instruction, with the exception of the Real Event Task. On the pre-test, the Real Event Task involved a series of situations all based on a dime placed on a piece of cardboard which in turn could move along a suspended, sloping metre rule. On the post-test, the situations were based on a dime placed on a block of wood which was in turn placed on an inclined plane. That is, the two events had differing surface structures and identical deep structures.

The Pittsburgh group

The instructional group comprised 13 middle school students selected from school districts in Allegheny County. These students were all designated as academically gifted by the Pennsylvania Department of Education and all had demonstrated an interest in science out of school. The instruction occupied one day per week for eight weeks. A control group of 10 was selected from the same school district by use of the same criteria. This group was also given the cognitive structure probes on two occasions separated by eight weeks, but did not experience any special program in this time.

At this stage, the data from the three group tests (free sort, tree construction, word association) has been analyzed. Proximity matrices have been produced from responses to each of the three tests and scaling methods applied to these matrices to produce representatives of cognitive structure. Latent partition analysis (LPA), multi-dimensional scaling (MDS), and hierarchical clustering (HC) methods were applied to the proximity matrices from each of the three tests, with the exception of the word association matrix to which LPA cannot be applied. Hence

eight representations of group cognitive structure resulted. An outline of the procedures adopted for analysis of responses to each of the three tasks follows.

Free Sort Task

The response of each student for this task consisted of a number of concept groupings, each containing one or more of the 17 concepts. Lists of the groupings in which each student placed each of the concepts are the initial input to the LPA computer program (Harasym & Pecht, 197). From these lists, a 17 x 17 joint occurrence matrix is computed whose cells (i,j) show the proportion of students who placed concepts i and j in the same grouping. This joint occurrence matrix serves as the group proximity matrix to which the LPA is applied. (The same proximity matrix also is used in the MDS and HC scaling methods.) The number of latent categories which the LPA program solved for may be specified either by the researcher (on the basis of a theory or some other a priori reason) or by the program (whose criterion is the number of eigen values greater than 1). We have found the program's criterion to yield solutions that are superior to those where the researchers prespecified the number of derived latent categories.

Tree Construction Task

The tree (linear non-directed graph) constructed by each student is composed of the 17 concepts connected by 16 lines, each labelled with a number reporting the place in the sequence that the connection was made. The sum of the sequential numbers between any two concepts is taken as the distance between these concepts, and these distances comprise the entries of a 17 x 17 proximity matrix for each student. The individual proximity matrices are summed to obtain the group proximity matrix, which is the input for the MDS and HC analyses. For the MDS analyses, we use

the KYST computer program (Kruskal, Young, & Seery, 1973). The HC analyses are carried out with the HCLUST computer program (S.C. Johnson, 1967). The hierarchical clustering scheme produced as the program's output shows only the clustering history, i.e., the order in which the concepts were grouped by the program. It is necessary to pick a certain level of the clustering as the significant level, being representative of the process, which will then be subjected to conceptual domain related analysis. To this end, we employed the procedure proposed by Hubert and Baker (1976), which is based on the computation of Goodman and Kruskal's (1954) Gamma coefficients for the whole set of clusterings and for each level of clustering. The first, overall, coefficient is used to test the null hypothesis of no systematic structure in the clustering scheme. The gamma coefficients for every clustering level are used to identify the level that will be chosen for further analysis, being identified as an exceptional one regarding the trend of either the obtained gamma coefficients or their percentile rank. A partition of the concepts was obtained for each student by considering every subtree of her/his original tree as a category. The resulting partition is treated as that obtained by FS task, and is used to form a 17 x 17 joint occurrence matrix that was subjected to LPA.

Word Association Task

For each of the five concepts used as stimuli, the WA Task yields an ordered list of words which the student associates with the given concept. From these lists, a 5 x 5 individual proximity matrix is computed of the entries which are the relatedness coefficients between any two stimulus concepts. The relatedness coefficient (Garskoff & Houston, 1963) for any two concepts (with p = 1) is a measure of the overlap in both order and content between the lists of words associated

with the two concepts. The average proximity matrix which is obtained by averaging the individual means of the proximity matrices is the input for the HC and MDS analyses.

Findings and Discussion

The extent to which convergence is observed in the numerous representations of cognitive structure which could be obtained from the combination of all proximity matrices and all scaling methods used is not taken up here (see Champagne & Klopfer, Note 4). Rather, our focus is on comparisons between pre- and post- test cognitive structure representations for the Instructed and Control groups.

There are difficulties with the Pittsburgh data from the Word Association Task. Relatedness coefficients for pre- and post- test data from the same group are generally low and sometimes zero. A large number of terms appear on the lists of associations, but there is little overlap in the terms individuals give as associations. There is also little overlap in the lists of terms given by the same student on two occasions or by the same group of students on two occasions. These observations are consistent with the information about the nature of the associations produced by the sentence generation task. Taken in conjunction with the substantial stability in representations of group cognitive structure suggested by other analyses (see below), these analyses and observations of the Pittsburgh Word Association data were interpreted as suggesting that these data were too unreliable to permit valid analyses. Hence no further analyses are reported.

The above finding is difficult to interpret. Both in a previous study in which an identical Word Association Task was used in a pre- and post- instruction context (Gunstone, 1980) and in the Victorian section of this study quite contrary observations have been made. Since these

latter uses involved Grade 11 and teacher training students respectively, the age of the Pittsburgh students might provide an explanation. It is logically reasonable to suggest that the Pittsburgh Word Association observations result from students of this age having cognitive structures in this content area which are, relative to older students, poorly articulated and unstable in terms of propositional knowledge. However no support for this hypothesis exists beyond the general perspectives we have formed from working in this content area with middle school students.

As indicated above, analyses suggest little change in the cognitive structures of the Pittsburgh students, taken as a whole group. For every combination of the two remaining data-gathering tasks and three scaling methods used: (a) the cognitive structure representations of the Instructed and Control groups derived from the pre-test are quite similar; (b) the cognitive structure representations of the Control group derived from the pre- and post-tests are quite similar; (c) the cognitive structure representations of the Instructed group derived from the pre- and post-tests are quite similar (and, as a consequence of (a)-(c), (d) the cognitive structure representations of the Instructed and Control groups derived from the post-test are quite similar). Only one set of representations is presented here as this set is typical of the consistency evident in all representations. Figures 1-4 show two dimensional configurations derived from the Free Sort Task data for Instructed group pre- and post-test and Control group pre- and post-test respectively. These representations depict the 17 concepts located in a two-dimensional space as this form was chosen as the optimal solution from the application of multidimensional scaling. Both visual comparisons and calculated indices of goodness of fit for each pair of cognitive structure representations suggest considerable stability in the cognitive structure of the Instructed group.

This failure of the instruction to change these particular cognitive structure representations has a number of possible interpretations. We advance three. (1) Our previous work points to the difficulty of changing cognitive structures associated with the interpretations of events which are part of the students' real world. In the area of introductory mechanics considered in this study in particular, there are grounds for arguing that pre-instruction conceptions derived from experience are more resilient than are conceptions in other science areas. (2) The possible explanations for the unexpected characteristics of the Word Association Task data presented above may be relevant here. That is, the failure to detect change in these cognitive structure representations may be a result of students of this age having cognitive structures in this content area which are not well articulated and are frequently unstable in terms of propositional knowledge. Given this, one could argue that the stability in representations may result from the nature of the task, and might not be found in other data. This leads to a third possible interpretation. (3) Although no change was found in the representations of cognitive structure, there were differences in the Instructed group pre- and post-test responses to the Free Sort Task. These differences are suggested both by inspection and by the correlations of the proximity matrices derived from the pre- and post-test responses of both groups. The correlations may indicate some changes in Instructed group cognitive structure, but further analysis and thought is needed before any claim of change is advanced.

The Victorian group

The students involved in the Victorian part of the study were science graduates undertaking a one year course in teacher training at Monash University with the aim of teaching high school biology or chemistry. In the Victorian context this means that they would also teach general or integrated science in years 7-10 of high school, and thus be involved in teaching physics concepts. As all of our work on instruction to change physics cognitive structures prior to this study had been with middle school students, a pilot program was run with eight trainee teachers. None of the data from this trial is reported here.

Because of course and administrative constraints, the group involved in the study proper were all volunteers. The choice to join the group was made on the basis of information describing what would take place as being "Physics for Non-physicists" directed towards developing an understanding of important ideas in elementary physics. Students had the option of joining this group or one of thirty or so others which ran across the total spectrum of issues of possible relevance to trainee teachers.

The group comprised six students. It is clear, given the circumstances described above, that all six both saw their understanding of physics to be inadequate and had considerable motivation to try to rectify this situation. The group met for two full days each week. The first day of the first and fourth weeks was given over to the group and individual tests of cognitive structure. Thus the instruction occupied five days. A control group was generated, again by calling for volunteers. However the resulting group differed considerably from the Instructed group in terms of phyics background, and consequently the control group data are

not considered here. This problem emphasizes that the Instructed group cannot be considered a representative sample of the population of prospective secondary science teachers who have inadequate training in physics.

Because of the nature of the group, there were some differences in the conduct of the study by comparison with Pittsburgh. The Victorian students reacted individually (in writing) to the experiences of each day and to the whole sequence. In addition they gave on the first day relevant biographical data and their perceptions of the areas of physics they believed they understood or did not understand. Discussions with the group tended to run for longer periods of time and cover a wider variety of relevant issues than was the case with the Pittsburgh group.

The same five cognitive structure probes were used pre- and post-instruction. Thus far the analyses of these data have been quite different from the Pittsburgh analyses, being more global, having a stronger focus on the individual probes than on the group probes, and including inspection of the transcripts of the instruction sessions. The major reasons for this approach being the first consideration of the data are the very different pre-instruction cognitive structures of the group (as compared with the Pittsburgh group) and the clear indications through the period of the study of changes in the ways individuals interpreted physics-based events and issues (and, therefore, the implication that cognitive structures had been changed).

Findings and Discussion

All six students had undertaken physics at years 11 and 12 at high school (the normal mode of school physics study in Victoria) and four had completed first year university physics. All were biology or chemistry majors. Four claimed to understand basic mechanics when given open-ended

questions about their knowledge of areas of physics at the first session, one stated he did not understand vectors and another that he did not understand mechanics but did understand forces. Given the extent of physics courses undertaken, it would be expected that the students would have some knowledge of school physics. Within limitations this was the case, as is discussed below. Where individuals are identified in the discussion, C, I, J, L, N and Z are used. C and J are female.

Data from the Word Association Task did not show the characteristics evident in the Pittsburgh data. At the analysis-by-inspection level used thus far, much more consistency is evident. Just over 50% of pre-test associations were repeated in the same sense (as judged by the sentence produced for each response) on the post-test). A significant number of non-repeated responses were synonyms and examples (e.g., in response to "change of motion" - stop, start, slow down, veer; to "force" - gravitational, electric, magnetic, nuclear). Although the pre-test produced a considerable number of propositions, there were relatively few relationships. Associations reflecting F = ma were given by all, but the accompanying propositions indicated a lack of precision in the view of this relationship. The above comments do not apply to J whose associations were more precise and reflected something nearer to a physicist's view.

In every case but one (Student I) the first chosen pair of concepts in the Tree Construction Task were descriptive and kinematic (e.g., speed-velocity, displacement-distance). This observation is interesting in terms of the view expressed by Easley (quoted at the beginning of the paper). In the Free Sort Task there was a tendency for groupings to be formula-based.

The request for definitions which is part of the ConSAT Task caused difficulty for all students. While all students sorted all concepts into

the "recognized" pile except for N who had two "unrecognized", there was universal unease about the request for definitions. Although demonstrably incorrect definitions were rare, attempts which were sufficiently vague as to be inadequate were relatively common. Even vagueness was not always reached for more abstract concepts such as inertia. The subsequent concept maps, in most cases, reflected these problems. Inertia was most commonly placed on the map with considerable difficulty. Links beyond the initial joining of two concepts were rare. As for the Word Association Task, student J was an exception. Her concept map was more integrated and her definitions both more precise and more confidently advanced.

All students gave predictions consistent with subsequent observations for situations in the Real Event Task. However only one (student J) consistently used a force analysis in explaining this series of statics and dynamics situations. The other five, to varying degrees, explained in terms of the surface features of the demonstration rather than the underlying physics. Both these explanations and the reactions to the set of provided answers produced a number of incorrect statements about forces and motion.

In general, with the exception of J, the pre-instruction cognitive structures of the students were characterized by the presence of relationships in the form of formulas which were not utilized for real events or other applications, by the presence of considerable propositional knowledge which lacked specificity and was occasionally incorrect. A very brief summary of these features emerged at the beginning of the first instructional session. The first task in this session was to consider the question "What are some of the things we can say about the relationships between force and motion?" Students recorded concensus answers on a blackboard. A facsimile of that blackboard is given in Figure 5. This blackboard summary remained throughout the period of instruction, with

modifications being made as students saw these to be necessary. It is interesting to note that an early response given to the beginning question in the first session was "F = ma". All agreed this was an appropriate answer but, when then asked to explain what it meant, no student was prepared to volunteer an answer.

In their reactions to what was happening written after each instructional session all students made claims which suggest that changes were occurring in their cognitive structures. Their reactions are summarized before the post-instruction probes are discussed.

After the first session, all wrote in terms of "I don't understand what I thought I did" and all indicated a positive motivation to the experience. This positive reaction was apparently contributed to by a long discussion about normal reaction forces. During this discussion (as shown by the transcript) considerable steps were taken towards reconciling an intuitive view of force being a dynamic entity associated with movement with existing knowledge from physics courses that a normal reaction force should be considered. In other words, as well as having their beliefs about their own understandings shaken, they also perceived that their understanding had increased in one area. The second session was largely devoted to prediction, observation and discussion of falling bodies. (The actual instruction in this session is discussed more fully in the conclusion.) Student reactions after this session indicated considerable change in their views about physics learning:

> ... enabled me to see how others view things and why they view them this way. Made one think hard to get a totally convincing argument for your side and any inability to do this gives you the suspicion that you are not in fact correct in your initial explanations ... helps in understanding our false misconceptions and being confident in our new ideas. (Student N)

... during [the] group discussion I changed my mind about the forces operating on the falling bodies .... Some people fight hard not to change preconceived ideas. (Student I)

It feels strange to contradict oneself half an hour later. It's worth the lengthy time involved because I can have time to gradually understand the issue at point. ... [it's] as if we are trying to turn a blind-eye to the truth. It's comforting to try to keep certain ideas forever even if there's a chance that they may be wrong. (Student Z)

I'm shattered! Didn't realize how devastating it could be to have a deep rooted belief proved wrong. Can I blame my physics teacher? It would be all right if some dummy didn't pose a question which could be used to support the opposite argument. Seriously though, very instructive.

I don't know if I'm going to be able to last the distance. I'm mentally exhausted after each session and the effort to hold out when I'm wrong is very draining. Great fun so far even if I hate it at odd times. (Student C)

Even though I had the correct idea today that acceleration is approx. constant, at first I could only say that the forces were different by using F = ma. After having to think of 'arguments' for this, I could justify it from an observational point of view. ... The open discussion and justification of ideas is a brilliant way toward understanding physics. Substituting numbers in formulas seems to be a poor alternative. (Student L)

Student J, whose pre-instruction data suggested a more comprehensive relevant cognitive structure, gave physically appropriate predictions and explanations for all situations used in session 2. However even she reported that "my very first impulse was to claim that equal forces were acting on the balls [of different mass]".

The general trend evident in the above quotes continued through the remaining session reactions although not elaborated in such detail. For example, for student C, "I don't smart so much any more" [after session 4], "Becoming more receptive to change in my supposed convictions" (after session 5). The written reactions to the whole sequence of instruction were also very consistent with the above quotes from session 3 reactions. Students all expressed the belief that their views had changed (with all giving detail of at least some of these changes). The importance of discussion, of considering the views of others, of relating a situation under consideration to other real world phenomena were all seen to be important in promoting changes of view.

The blackboard summary at the end of the instruction is represented in Figure 6. The progressive changes evident in this figure had been made in response to the question "Is there anything you would like to change on the blackboard?" at the end of sessions 2, 4, and 5. Students were not specifically asked to add additional statements, only to consider modifying what was there. This final summary shows less imprecision and more correctness (in terms of the physicist's view of force and motion).

The post-instruction probes of cognitive structure suggest that the cognitive structures of 4 of the students have been changed in the ways they reported through the instruction. The exceptions are student J (who, in simple terms, had less to change in her cognitive structure), and student N.

The most powerful, even though general, evidence of a change in cognitive structure comes from the Real Event Task. All students except N immediately described the situation used as being the same as that used in the pre-test despite the two situations having quite different surface features. All but N consistently used the underlying physics principles to explain their predictions and their evaluations of the provided set of answers. Student N showed some tendency to do this, but was not consistent. Only student N used imprecise statements in responding to the situations.

The definition task involved in the ConSAT was much more positively approached and much more appropriately answered. Impression was evident in "mass" and "inertia" definitions from student N and "inertia" from student C. Concept maps, by comparison with the pre-test maps, showed more connections and greater precision in connections.

On the Tree Construction Task, the most related pair of concepts was seen to be "mass" and "inertia" by students I, J and L. The remaining three selected a pair of descriptive, kinematics terms as they had done on the pre-test. The Word Association data showed a decrease, relative to the pre-test, in synonym and example responses for all students. However the total associations given increased by 29%, and by about 40% for the abstract concepts "force", "mass", "inertia". Increases were much smaller for the more familiar descriptive terms "speed" and "change of motion". Incorrect propositions on this task were very infrequent and there was much more precision evident. Relationships between concepts were more frequent than on the pre-test.

Conclusion

We cannot claim to have changed the cognitive structures of the Pittsburgh group, but appear to have been considerably more successful with the Victorian group. Some possible interpretations of the Pittsburgh finding have already been advanced in the Findings and Discussion section of that part of the paper. Hence this brief conclusion concentrates on the positive Victorian findings, although it is recognized that had identical modes of data analysis been applied to the results from each of the groups different conclusions may have been drawn.

Given the pre-test and personal data from the Victorian group, the most obvious explanation of the positive effect of instruction is that these students knew more physics to begin with than did those in the Pittsburgh group. It is consistent with the data to suggest that the Victorian students had a quite reasonable share of propositional statements based on a physicist's view in memory before the instruction, and that the instructional experience enabled them to both place some conceptual structure on this knowledge and to reconcile the knowledge with interpretations of the real world.

Our intention before the event was to try to identify features of the instruction which promoted changes in cognitive structure. It is clearly only worthwhile to undertake this process with the Victorian students.

Careful inspection of the transcripts of the Victorian instruction sessions, taken in conjunction with the student reactions to these sessions and the pre- and post- test data, does not suggest a single and dramatic "flash of inspiration" effect (nor did we expect one). However it is clear that the second session was of great significance. (It is the second session student reactions which were quoted at length above.)

In this session, students began by predicting the relative times of fall for 2 spheres of about 10 cm diameter when dropped from about 2 metres. One sphere was lead, the other a plastic ball. Although all predicted equal times, four (C,I,N.Z) said this would be the case because the same force acted on each sphere. This difference was debated at length. The process was then repeated for the spheres dropped from a height of about 12 metres (for which there is unquestioned difference in the time of fall), for two cubes of identical volume and different mass dropped about 0.25 metre in water, and finally for the two cubes dropped the same distance in oil. This process occupied about 5 hours (with coffee and lunch breaks not included). Transcripts and students' reactions make it clear that the first part of the next session - discussion of a demonstration of two carts of different mass being pulled by identical forces at the same time - should be seen as part of this sequence.

The significance of this sequence in changing cognitive structure lies not in the specific content per se but in the way in which this content promoted strongly held alternative views and lengthy and voluble debate. This particular sequence resulted in changes in specific cognitive structure (suggested by transcript of the session) but, more importantly, resulted in all students indicating that they began to understand the origin and resilience of views which caused them to be conceptually troubled by the perspectives advanced in physics courses. It was common through the remainder of the instruction for individuals to overtly use the second session experience to argue to themselves and others about internal consistencies in their interpretations of events and inconsistencies between these interpretations and the tenets of physics.

It seems likely that there are two factors of significance in considering the differences in effect on the two groups. The greater

knowledge before instruction shown by the Victorian group has already been mentioned. The other factor is the age and motivation of the Victorian students. These students were prepared to continue debate on an issue for extreme lengths of time. They were also, because of both their maturity and concern with their development as teachers, anxious to be introspective about their learning during the instruction and the origin of their existing ideas.

In summary, we have then changed cognitive structures in a content area for which we have found this process to be very difficult. However we have achieved this only with mature and motivated students with a reasonable store of existing propositional knowledge, and not for all students (the evidence suggests student N was not moved as far as the other students). On a more positive note, the changes achieved came in what we regard to be the remarkably short time of five instructional days and were changes which involved an understanding of learning which may well be applied by the students to other content areas.

Reference Notes

1 Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. A model of adolescents' understanding of physical phenomena and its application to instruction. Paper given at the meeting of the American Educational Research Association, Los Angeles, April 1981. (ED 202 670).

2 Champagne, A.B., Klopfer, L.E., Solomon, C.A., & Cahn, A.D. Interactions of students' knowledge with their comprehension and design of science experiments.

3 Gunstone, R.F. Cognitive structure and performance after physics instruction. Paper given at the meeting of the American Educational Research Association, Los Angeles, April 1981. (ED 202 703).

4 Champagne, A.B., & Klopfer, C.E. Construct validation of the cognitive structure of science concepts. Manuscript in preparation.

References

Champagne, A.B., Klopfer, L.E., & Anderson, J.H. Factors influencing the learning of classical mechanics. American Journal of Physics, 1980, 48, 1074-1079.

Champagne, A.B., Klopfer, L.E., Desena, A.T., & Squires, D.A. Structural representations of students' knowledge before and after science instruction. Journal of Research in Science Teaching, 1981, 18, 97-111.

Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. Cognitive research and the design of science instruction. Educational Psychologist, 1982, 17, 31-53.

Easley, J.A. Scientific method as an educational objective. In L.C. Deighton (Ed.) The encyclopedia of education. New York: Macmillan & Free Press, 1971, 8, 150-157.

Fillenbaum, S., & Rapoport, A. Structures in the subjective lexicon. New York: Academic Press, 1971.

Garskoff, B.E., & Houston, J.P. Measurement of verbal relatedness: An idiographic approach. Psychological Review, 1963, 70, 277-288.

Goodman, L.A., & Kruskal, W.H. Measures of association for cross-classification. Journal of the American Statistical Association, 1954, 49, 732-64.

Gunstone, R.F. Structural outcomes of physics instruction. Unpublished doctoral thesis, Monash University, 1980.

Gunstone, R.F., Champagne, A.B., & Klopfer, L.E. Instruction for understanding: A case study. Australian Science Teachers Journal, 1981, 27(3), 27-32.

Gunstone, R.F., & White, R.T. Understanding of gravity. Science Education, 1981, 65, 291-300.

Hubert, L., & Baker, F.B. Data analysis by single-link and complete-link hierarchical clustering. Journal of Educational Statistics, 1976, 1, 87-111.

Johnson, P.E. Word relatedness and problem solving in high school physics. Journal of Educational Psychology, 1965, 56, 217-224.

Johnson, S.C. Hierarchical clustering schemes. Psychometrika, 1967, 32, 241-254.

Miller, G.A. The organization of lexical memory: Are word associations sufficient? In G.A. Talland & N.C. Waugh (Eds), The pathology of memory. New York: Academic Press, 1969, 223-236.

Preece, P.F.W. Mapping cognitive structure: A comparison of methods. Journal of Educational Psychology, 1976, 68, 1-8.

Shavelson, R.J. Some aspects of the correspondence between content structure and cognitive structure in physics instruction. Journal of Educational Psychology, 1972, 63, 225-234.

Shavelson, R.J., & Stanton, G.C. Construct validation: Methodology and application to three measures of cognitive structure in physics instruction. Journal of Educational Psychology, 1975, 12, 67-85.

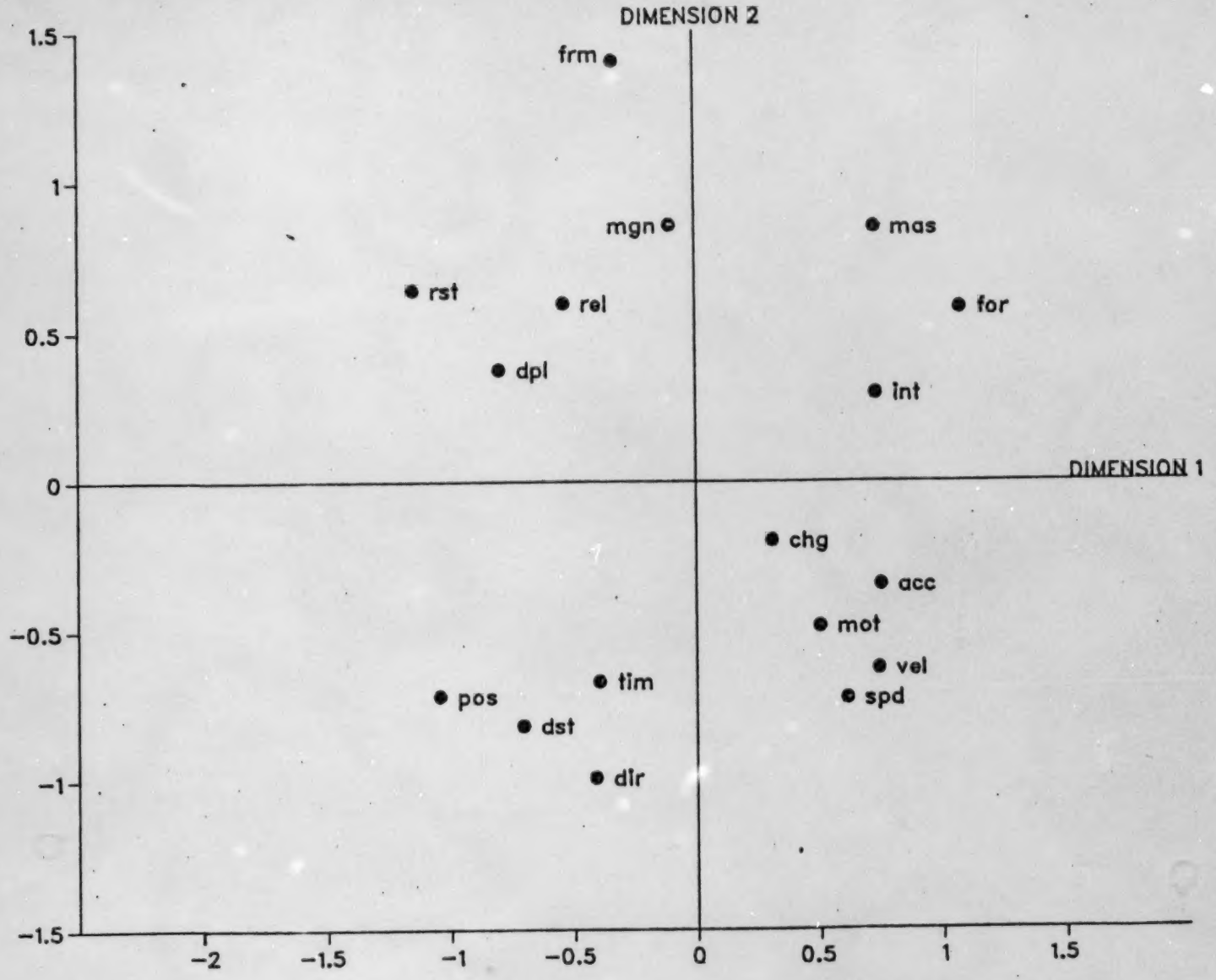

Figure 1: Rotated 2-D configuration of free sort task, instructed group, pre.

(Abbreviations used: acc - acceleration, chg - change of motion, dir - direction, dpl - displacement, dst - distance, for - force, frm - frame of reference, int - inertia, mas - mass, mgn - magnitude, mot - motion, pos - position, rel - relative, rst - resultant, spd - speed, tim - time, vel - velocity)

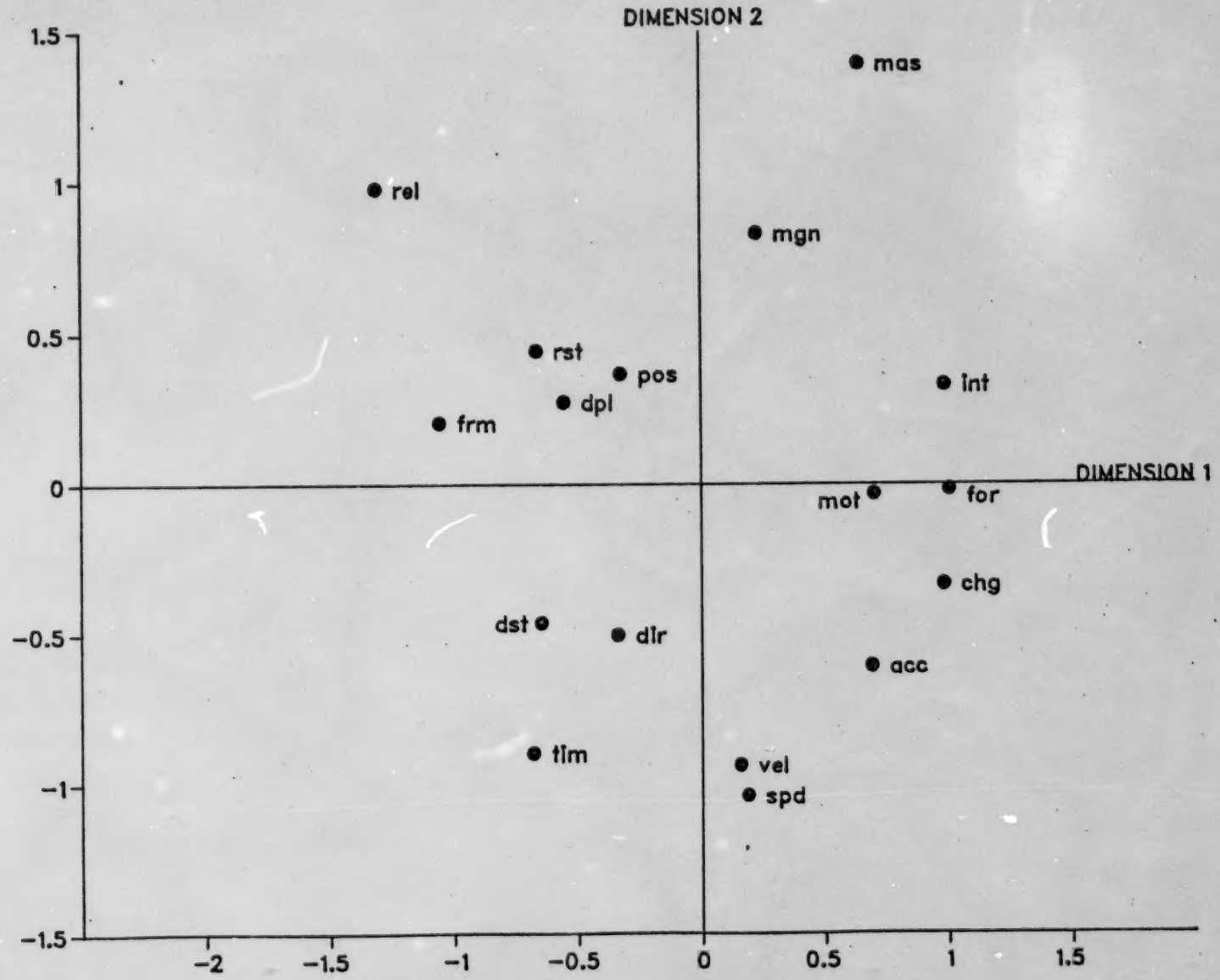

Figure 2: Rotated 2-D configuration of free sort task, instructed group, post. (Abbreviations explained on Fig. 1.)

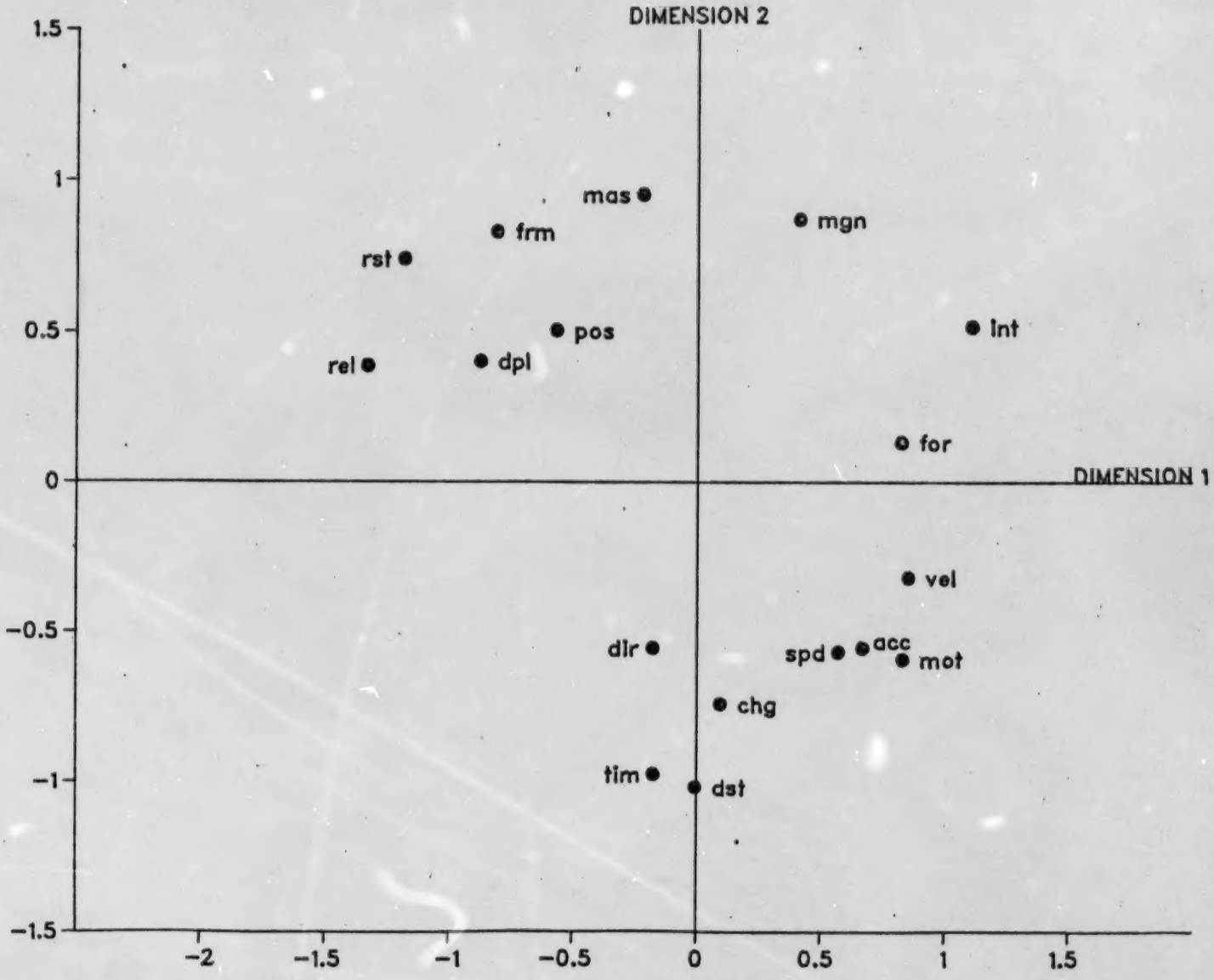

Figure 3: Rotated 2-D configuration of free sort task, control group, pre. (Abbreviations explained on Fig. 1.)

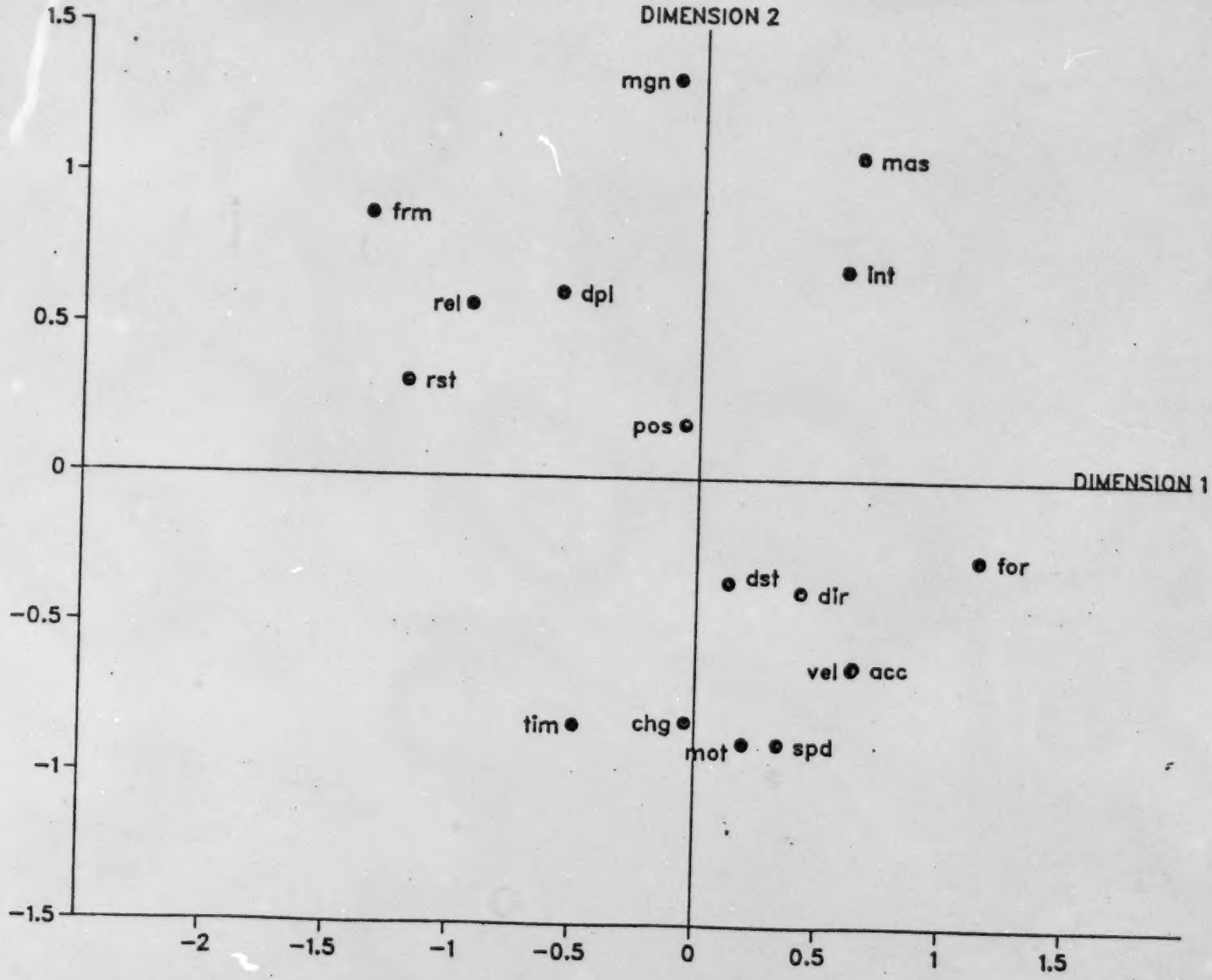

Figure 4: Rotated 2-D configuration of free sort task, control group, post. (Abbreviations explained on Fig. 1.)

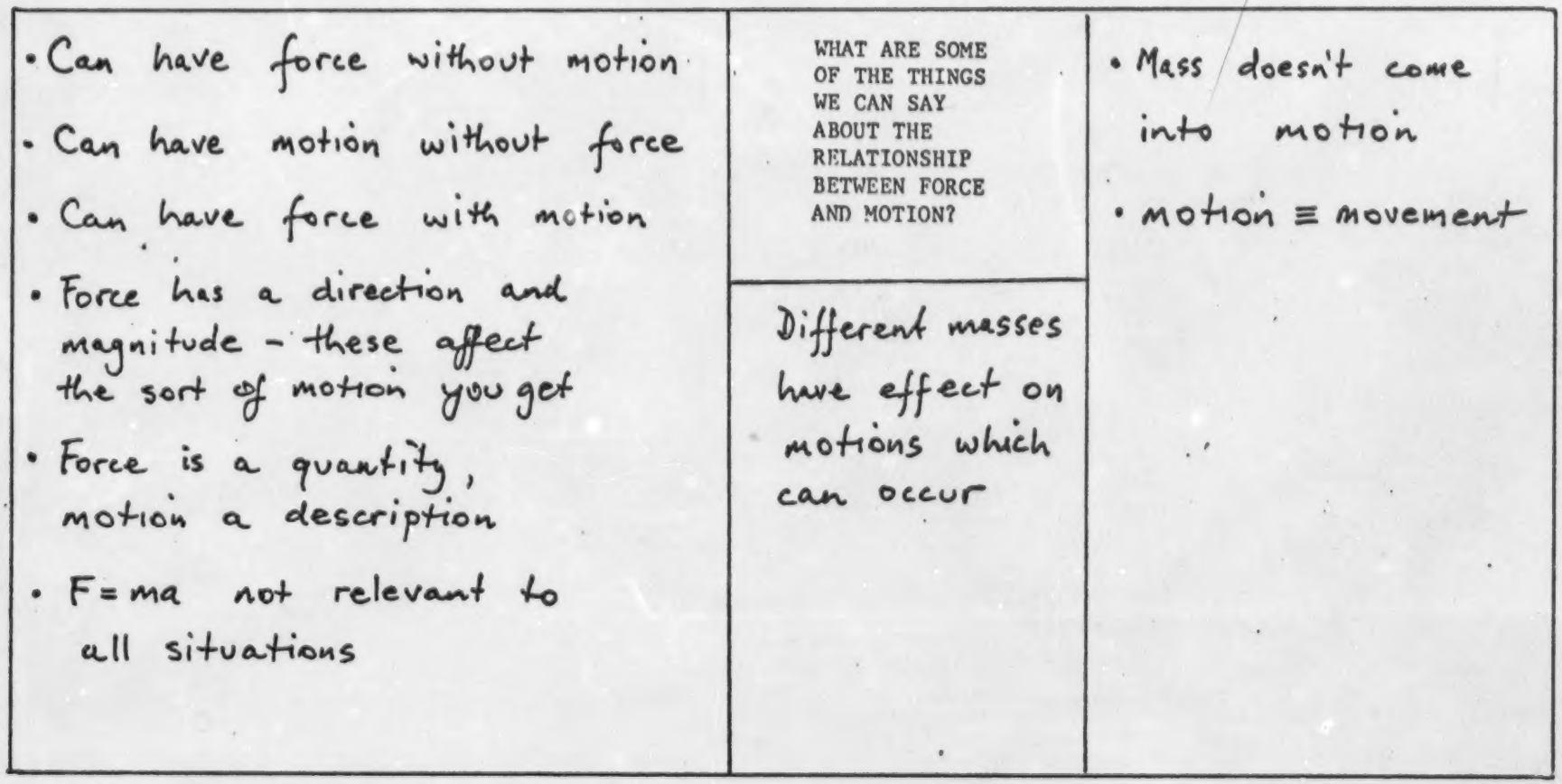
• Can have force without motion
• Can have motion without force
• Can have force with motion
• Force has a direction and magnitude - these affect the sort of motion you get
• Force is a quantity, motion a description
• F=ma not relevant to all situations
WHAT ARE SOME OF THE THINGS WE CAN SAY ABOUT THE RELATIONSHIP BETWEEN FORCE AND MOTION?
Different masses have effect on motions which can occur
• Mass doesn't come into motion
• motion ≡ movement

Figure 5: Blackboard summary after first segment of first instructional session.

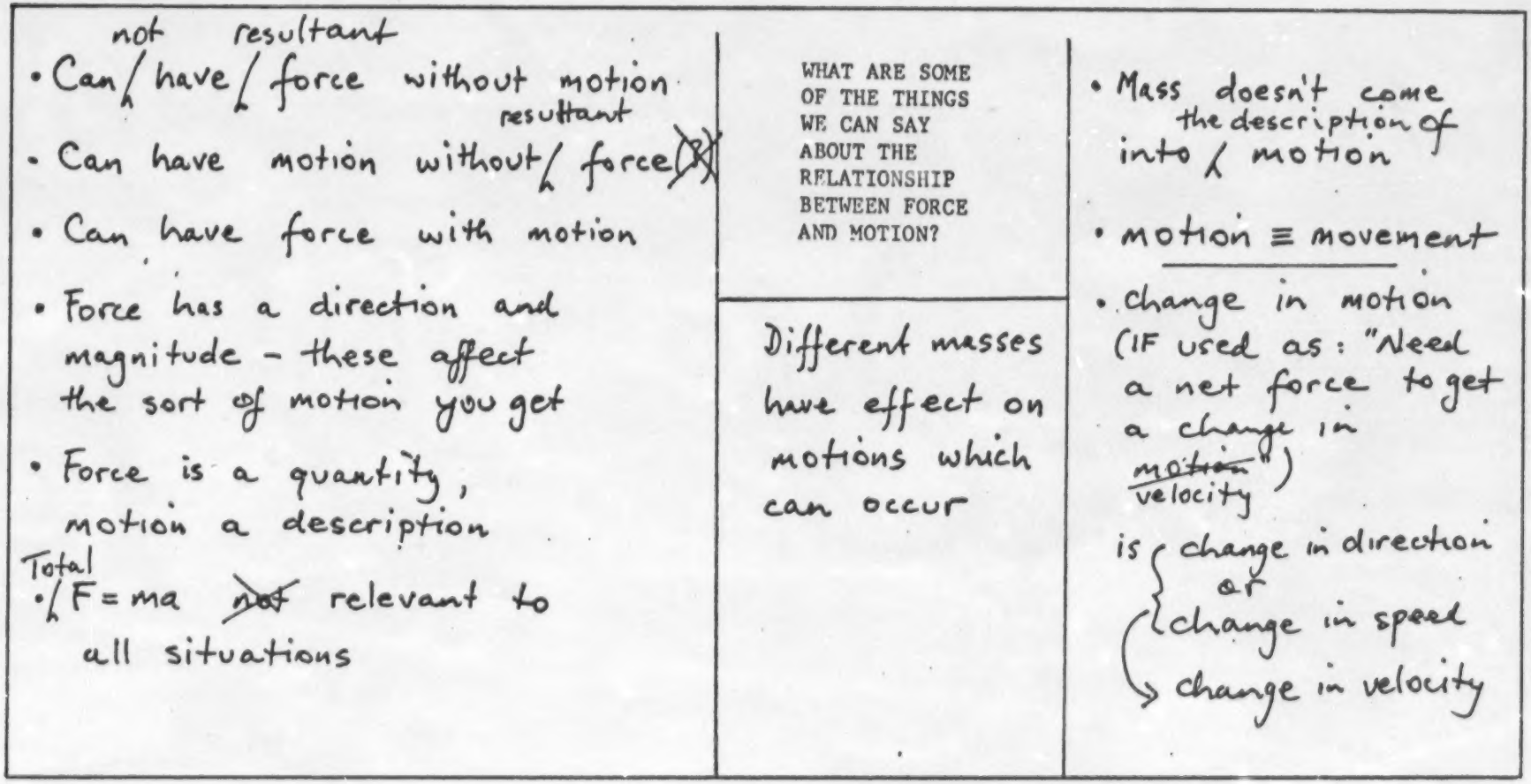
• Can not have resultant force without motion
• Can have motion without resultant force
• Can have force with motion
• Force has a direction and magnitude - these affect the sort of motion you get
• Force is a quantity, motion a description
• Total F = ma not relevant to all situations
WHAT ARE SOME OF THE THINGS WE CAN SAY ABOUT THE RELATIONSHIP BETWEEN FORCE AND MOTION?
Different masses have effect on motions which can occur
• Mass doesn't come into the description of motion
• motion ≡ movement
• change in motion (IF used as: "Need a net force to get a change in motion/velocity")
is change in direction or change in speed
change in velocity

Figure 6: Blackboard summary at completion of instruction.